RESEARCH DEPARTMENT

Stereophony: The effect of differences between the phase-frequency characteristics of left and right channels

RESEARCH REPORT No. L-049/3

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THE BRITISH BROADCASTING CORPORATION

ENGINEERING DIVISION

RESEARCH DEPARTMENT

STEREOPHONY: THE EFFECT OF DIFFERENCES BETWEEN THE PHASE-FREQUENCY CHARACTERISTICS OF LEFT AND RIGHT CHANNELS

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(1964/8)

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SUMMARY

In a stereophonic transmission system, differences between the phase-frequency characteristics of the left- and right-hand channels may result in displacement or dispersion of the sound images across the stage, and may also impair the volume or quality of the compatible monophonic programme.

These effects have been subjectively assessed for the case, common in practice, in which the unintentional interchannel phase difference is proportional to frequency at the upper end of the range and inversely proportional to frequency at the lower end. The experiments were carried out as a contribution to the work of the EBU in establishing performance limits for stereophonic transmission systems; the tolerances on interchannel phase differences finally recommended by the EBU are given in an Appendix.

1. INTRODUCTION

The position of the virtual sound image produced by applying a pair of correlated signals to two loudspeakers depends not only on the relative amplitudes but also on the relative phases of corresponding components in the left- and right-hand channels respectively. In the transmission of stereophonic programmes, therefore, disparities between the phase characteristics of the two channels may lead to unwanted displacement of the images, and where this displacement is a function of frequency, the various components of a complex sound may be dispersed across the stage. It is therefore important, in planning a distribution system for stereophonic programmes, to know what degree of mismatching between the phase characteristics of the left- and right-hand channels can be allowed without introducing appreciable changes in the stereophonic presentation. In the discussion which follows, the term 'interchannel phase (or time) difference' will be used for brevity to denote unwanted differences arising from lack of similarity between the channels, as distinct from any intentional difference in phase (or time) between the original left- and right-hand signals.

At frequencies for which the wavelength of the sound is greater than the dimensions of the human head, the image position is a function of the phase difference between signals in the left- and right-hand channels. At higher frequencies, however,

it is the envelopes of the left- and right-hand signals which are significant in directional hearing,[1] so that the relevant quantity is not the difference in phase between corresponding components but the difference in time of arrival of the signals as a whole. Any disparity between the phase characteristics of the two channels has therefore to be considered partly in terms of phase differences and partly in terms of differences in group delay time.

Little information has so far been published* on the influence, on a stereophonic image, of interchannel - as distinct from interaural - phase differences, except where this takes the form of a straightforward interchannel time delay. Early Research Department tests with pairs of lines having known differences in group delay time, supplemented by experiments in which known interchannel delays were introduced by magnetic recording devices, indicated that the minimum perceptible time difference was of the order of 250 μs.[2] Other investigators came to similar conclusions[3,4] and in 1960 a figure of 200 μs was provisionally adopted by the EBU Working Party S as the maximum allowable difference in group delay time between the left- and right-hand channels.

The above criterion is, however, open to two objections. In the first place, it fails to meet the requirement of multiplex transmission systems in which the sum of the left- and right-hand signals is used to provide a compatible monophonic programme. In such systems, differences in time delay between the two channels, if large enough, produce interference effects within the audio-frequency band which adversely affect the frequency characteristic for monophonic reception; thus, if the left- and right-hand signals are equal in amplitude, an interchannel time difference of 200 μs would produce a complete cancellation of the resultant monophonic signal at 2·5 kc/s, 7·5 kc/s and 12·5 kc/s. To guard against such effects, the EBU Working Party S in 1961 tentatively proposed an overriding requirement that the difference in phase shift between the left- and right-hand channels should be limited to 90°, a figure which can readily be shown to give a loss of 3 dB in the sum signal; the subjective effect of this loss depends, however, on the frequency at which it occurs and such a criterion could not therefore be accepted without further investigation. In the second place, the practice of specifying interchannel phase differences only in terms of time delay imposes unnecessarily stringent requirements at the lower end of the audio-frequency range; for example, a time difference of 200 μs corresponds at 50 c/s to a phase difference of only 3·6°, a figure which is known from experience to be negligible. To meet both these objections and also to obtain data on which practical tolerances for a broadcast distribution system could be based, it was therefore decided to carry out the subjective experiments described in this report. These cover the lower and upper regions of the audio-frequency band and take into account the quality of the monophonic programme as well as the impairment of stereophony.

For the purpose of these experiments, interchannel phase differences were divided into two categories:

(a) Phase differences existing between channels for which the bandwidths and the amplitude-frequency responses within the pass band are substantially identical.

(b) Phase differences associated with differences in amplitude-frequency response between the channels within the pass band.

* Reference 8 describes experiments carried out by I.R.T. concurrently with the work described in this report.

The experiments described in this report were confined to condition (a); a further investigation relating to condition (b) is covered in a later report dealing with the effects of an interchannel difference in frequency characteristic.

For case (a), it has been shown theoretically, and verified by measurements carried out by Designs Department,[5] that within the pass band of an equalized transmission channel, such as an S.B. line, the variations of phase shift with frequency may be represented, with a sufficient accuracy for the present purpose, by

$$\theta = K_1 f - K_2/f$$

where θ is the phase shift at frequency f and K_1, K_2 are constants for the channel. The phase difference between any two such channels can clearly be expressed in the same form, and the present experiments were designed to reproduce approximately this condition. The upper and lower ends of the frequency range were separately investigated, the interchannel phase differences being made proportional to frequency in the former case and inversely proportional in the latter; this approximation leads to a slightly higher interchannel phase difference in the mid-band region than would occur in practice.

2. GENERAL

The experimental arrangements for observing the stereophonic effects were generally similar to those adopted in earlier experiments on the subjective effect of interchannel crosstalk, with the observer centrally placed;[6] most of the tests were carried out in the standard listening room under simulated domestic listening conditions, but a few were repeated in a dead room having a wall reflexion coefficient of less than 10% for frequencies above 80 c/s. In assessing the effect of interchannel phase differences on the quality of the compatible programme, the signals from the two channels were combined and fed to a loudspeaker type LS5/1 in the listening room. The observer was seated at a distance of 1·5 m in front of the loudspeaker.

Existing data[1] indicate that the rate of change of image position with interchannel time difference is greatest when this time difference is small and when the interchannel amplitude difference is also small. The effect of interchannel phase differences on the stereophonic presentation may therefore be expected to be most noticeable when the original left- and right-hand signals are equal and in phase, i.e. when the stereophonic image is intended to appear to a central observer to be in the centre of the stage. The same condition is also the most critical for the quality of the compatible monophonic programme, since the variation in the sum of two signals which results from a variation in the phase angle between them is greatest when the two amplitudes are equal. To simulate this state of affairs, signals from a common source were applied to the two channels, the required interchannel phase shift being effected by all-pass networks introduced into one or the other. All tests were repeated with the left- and right-hand channels interchanged.

The team of observers consisted of thirteen engineering staff from Electro-Acoustics Group, all experienced in quality assessment.

3. INTERCHANNEL PHASE DIFFERENCE INCREASING AT HIGH FREQUENCIES

3.1. Effect of Interchannel Phase Difference on Quality of Compatible Monophonic Signal

3.1.1. Experimental details

In these tests, the phase shift network consisted of a series of delay networks giving phase shift proportional to frequency. Fig. 1, curve (a), shows

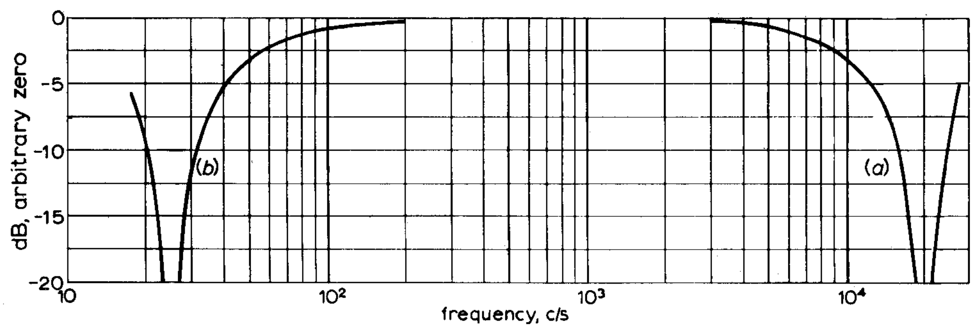

Fig. 1 - Frequency characteristics of compatible signal produced by the summation of identical left- and right-hand signals after transmission over separate channels

Curve (a): For interchannel phase difference proportional to frequency, reaching 90° at 10 kc/s (Interchannel time difference 25 μs)

Curve (b): For interchannel phase difference inversely proportional to frequency, reaching 90° at 50 c/s

the resulting frequency characteristic of the sum signal derived from a pair of identical left- and right-hand signals when the interchannel time difference was 25 μs, corresponding to an interchannel phase difference of 90° at 10 kc/s; for greater or lesser values of time difference the curve is displaced up or down the frequency scale. The amount of delay introduced into the circuit was varied in steps of 5 μs by a rotary switch under the control of the observer; additional delay, the amount of which was unknown to the observer, was introduced by the experimenter and varied from test to test, so that there was no fixed relationship between the setting of the rotary switch and the constants of the system. For each test, the observer was asked to find the switch position beyond which a change of quality of the programme became apparent, i.e. the point at which rotation of the control knob in one direction produced an audible change in quality while an equal rotation in the opposite direction had no effect. The degree of quality impairment corresponding to this setting of the control will for the sake of brevity be referred to hereafter as ‘imperceptible’.

The programme material consisted of recorded excerpts of Latin-American music - chosen because of its extended high-frequency range - solo violin and female speech. The test passages varied in duration from 7 seconds to 46 seconds; each passage was repeated again and again without a break until the observer had made his decision.

The tests were carried out under three conditions:

(i) with the audio-frequency bandwidth of the programme material limited only by the characteristics of the loudspeaker, the frequency range of which extends to 13 kc/s

(ii) with the upper frequency range of the material restricted to 10 kc/s by a low-pass filter

(iii) with a similar restriction to 6·8 kc/s.

As in previous experiments[7] involving impairment of quality by restricting the high frequency response of the programme chain, it was necessary to prevent the observer being influenced by changes in the spectrum of the background hiss, rather than in the spectrum of the programme; to this end, additional random noise, obtained from a gas discharge generator and sufficient to mask changes in the existing hiss, was injected into the circuit after the point at which the left- and right-hand signals were combined, but ahead of the low-pass filters.

3.1.2. Results

In Fig. 2, the interchannel time differences are shown as abscissae, while the percentage of tests in which the effect of the time difference was imperceptible are plotted to a Gaussian probability scale as ordinates. The line of best fit was arrived at by the method described in Report A-037; the standard error of the mean is indicated in each case.

Tables 1 and 2 show, for the three different bandwidths, the amount of interchannel time difference which was imperceptible in 50% and 90% of the tests

Interchannel Time Difference Imperceptible on Compatible Monophonic Programme

TABLE 1 - 50% of Tests

Item	UPPER FREQUENCY LIMIT 13 kc/s			UPPER FREQUENCY LIMIT 10 kc/s			UPPER FREQUENCY LIMIT 6·8 kc/s		
	Interchannel Time Difference	Interchannel Phase Difference at 13 kc/s	Loss in Compatible Signal at 13 kc/s	Interchannel Time Difference	Interchannel Phase Difference at 10 kc/s	Loss in Compatible Signal at 10 kc/s	Interchannel Time Difference	Interchannel Phase Difference at 6·8 kc/s	Loss in Compatible Signal at 6·8 kc/s
Latin American Music	22·8 μs	107°	-4·5 dB	29·7 μs	107°	-4·5 dB	36·3 μs	89°	-2·9 dB
Female Speech	27·6 μs	129°	-7·3 dB	32·5 μs	117°	-5·6 dB	44·1 μs	108°	-4·6 dB
Violin	32·6 μs	152°	-12·3 dB	37·0 μs	133°	-8·0 dB	45·5 μs	111°	-4·9 dB

TABLE 2 - 90% of Tests

Latin American Music	15·7 μs	74°	-1·9 dB	20·0 μs	72°	-1·8 dB	26·6 μs	65°	-1·5 dB
Female Speech	19·2 μs	90°	-3·0 dB	24·1 μs	87°	-2·8 dB	31·6 μs	77°	-2·1 dB
Violin	25·0 μs	117°	-5·6 dB	27·7 μs	100°	-3·8 dB	35·5 μs	87°	-2·8 dB

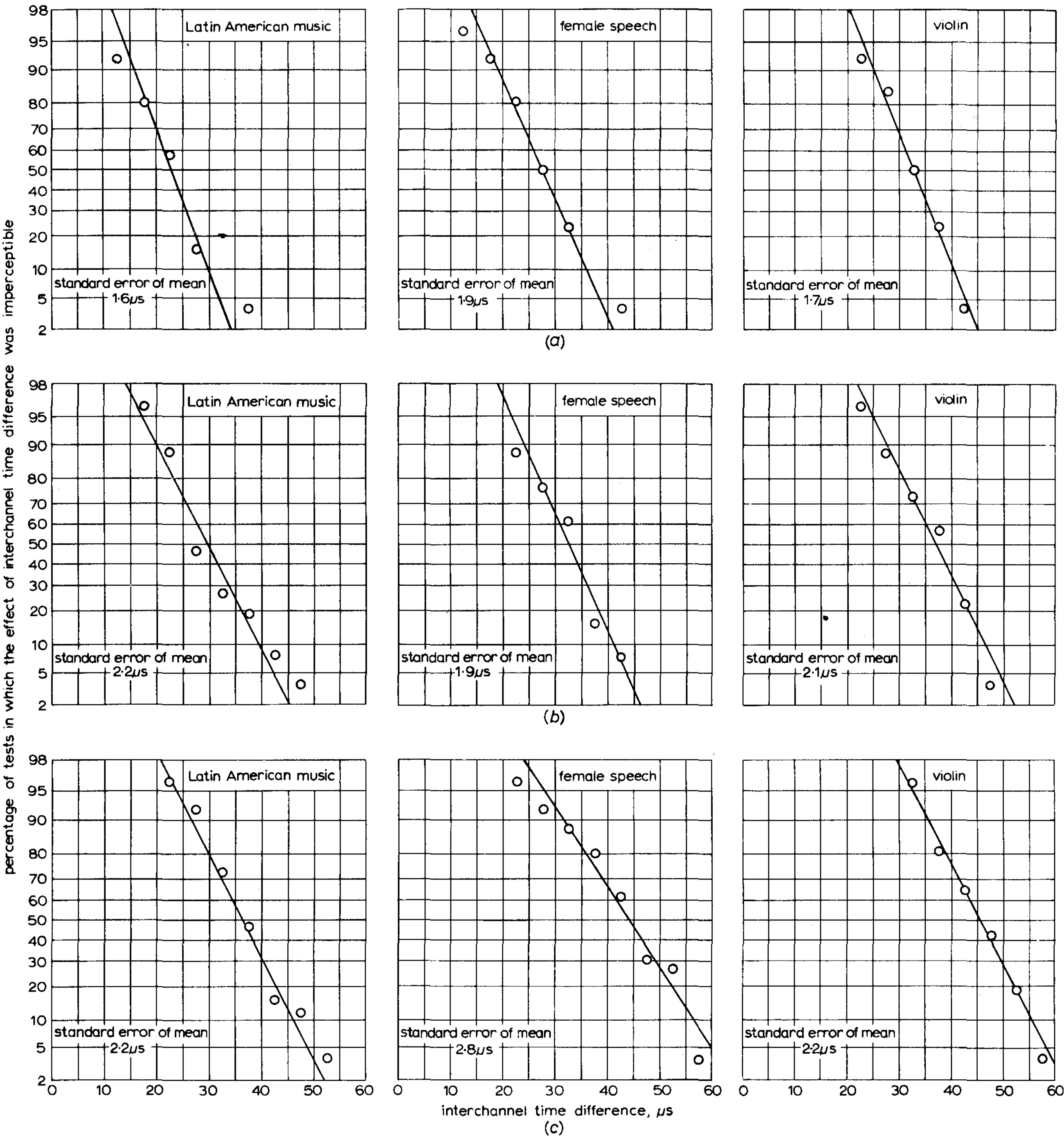

Fig. 2 - Effect of interchannel time difference on quality of compatible programme obtained by addition of identical left- and right-hand signals

(a) upper frequency limit of programme 13 kc/s
(b) upper frequency limit of programme 10 kc/s
(c) upper frequency limit of programme 6·8 kc/s

respectively. For each bandwidth, the second column of the table shows the corresponding phase differences at the upper limit of the band. The third column shows the loss, at the upper limit of the band, to which a compatible signal derived by adding equal left- and right-hand signals would be subjected.

The interchannel time difference found to be imperceptible varies, as might be expected, between the individual items; however, comparison of the smallest delay shown in Table 2 with the largest shown in Table 1 for the same bandwidth shows a ratio of less than two to one. It should be noted that restriction of the upper frequency range, while allowing greater time differences for the same impairment of monophonic quality, does not allow a greater phase angle, and hence a greater loss, to be tolerated at the upper end of the band.

In view of the suggestion, cited in Section 1, that the maximum allowable interchannel phase difference should be 90°, it is of interest to apply this criterion to the conditions of the present experiment. Since the phase difference here is proportional to frequency, the limiting case is that in which the figure of 90° is attained at the upper end of the band. The figures in Table 3, obtained by interpolation, show the percentage of tests in which the impairment of quality under these conditions would be imperceptible. It will be seen that with one exception - Latin American music restricted to the 6•8 kc/s range - the subjective effect of the interchannel phase difference would be imperceptible in more than 70% of the tests and may therefore be regarded as tolerable.

TABLE 3

Percentage of Tests in Which the Effect of Interchannel Phase Difference Proportional to Frequency and Reaching 90° at the Upper End of the Frequency Band Would be Imperceptible

ITEM	UPPER FREQUENCY LIMIT 13 kc/s	UPPER FREQUENCY LIMIT 10 kc/s	UPPER FREQUENCY LIMIT 6•8 kc/s
Latin American Music	74%	73%	48%
Female Speech	90%	87%	78%
Violin	99%	95%	87%

3.2. Effect of Interchannel Phase Difference on Stereophonic Presentation

As already indicated in Section 1, the maximum interchannel time difference which can be allowed without detriment to the stereophonic presentation is of the order of 250 μs. For the purpose of the present investigation, a more accurate determination of this figure is unnecessary, since, as shown in Table 1, a limit of the order of 25 μs is already set by the requirements of the compatible programme.

4. INTERCHANNEL PHASE DIFFERENCE INCREASING AT LOW FREQUENCIES

4.1. Effect of Interchannel Phase Difference on Quality of Compatible Monophonic Signal

4.1.1. Experimental Details

The programme material consisted of recordings of musical excerpts played respectively on organ, double-bass (pizzicato) and bass drum. The low-frequency limit of the system cannot be defined as unambiguously as the high-frequency limit; in fact, the spectrum of the programme material was found to extend down to 40 c/s, at which frequency the free-field response of the loudspeaker was 3 dB below the mid-band level. The interchannel phase difference was provided by an all-pass network giving a phase shift varying inversely as the frequency and reaching 90° at 50 c/s.

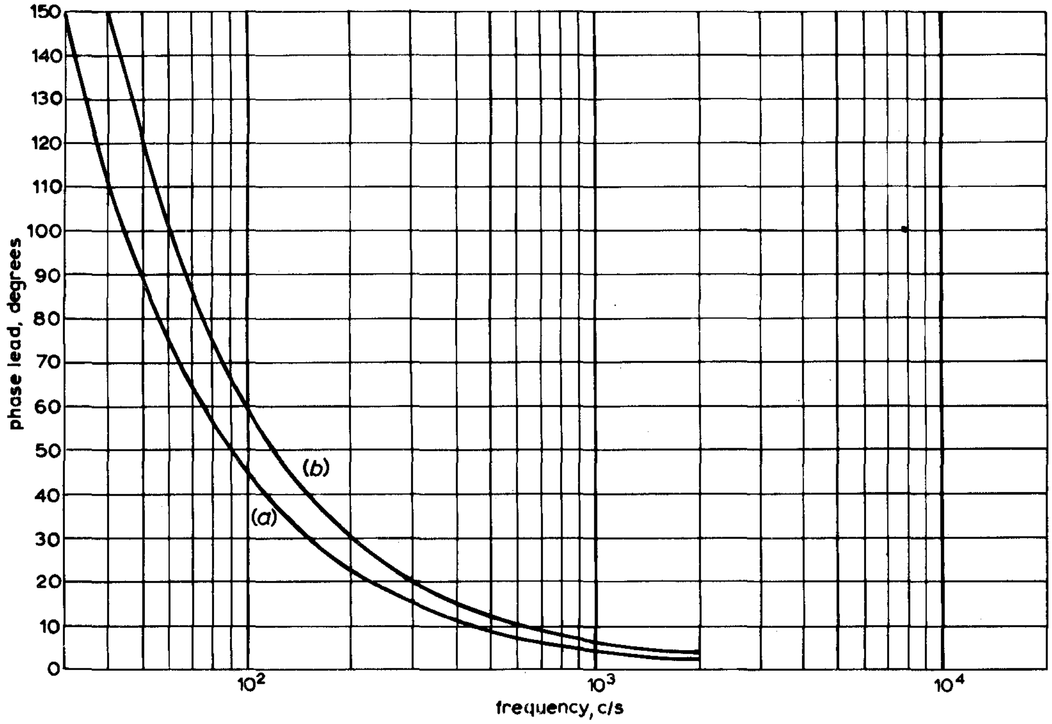

Fig. 3 - Phase-frequency characteristics of all-pass networks used for tests in low-frequency range

Interchannel phase difference inversely proportional to frequency

(a) reaching 90° at 50 c/s
(b) reaching 120° at 50 c/s

Fig. 3, curve (a), shows the variation of phase shift with frequency produced by this network and Fig. 1, curve (b), the resulting frequency characteristic obtained by taking the sum of the left- and right-hand signals.

The ability of the observers to detect the presence of the phase-shifting network in one channel was determined by a series of 'ABX' tests. In each such test, the chosen passage of programme was presented three times in close succession, the phase-shifting network being introduced at random in either one or two of the repetitions; the observers were then asked to say which of the first two conditions presented resembled the third.

4.1.2. Results

For the test passage on the bass drum, 67% of the observers correctly identified the test condition; for the organ and double-bass, however, the proportion of correct answers was respectively 54% and 53%, i.e. not much greater than the 50% figure which would have been obtained by chance. The effect, on the quality of the compatible programme, of an interchannel phase difference varying inversely with frequency and amounting to 90° at 50 c/s is therefore marginal.

4.2. Effect of Interchannel Phase Difference on Stereophonic Presentation

4.2.1. Experimental Details

The programme material was the same as that described in 4.1.1. Each test passage was presented a number of times with the phase shifting network referred to in Fig. 3, curve (a) alternately inserted and withdrawn; the observer was asked to state whether he detected any movement of the image, or of some component of it, and if so, in which direction. Although a high proportion of observers could detect the presence of the phase-shifting network (and the scores were found to increase slightly with practice) the movement of the image was too small to be estimated accurately. A further experiment was then carried out with a second all-pass network having a phase shift varying, as shown in Fig. 3, curve (b), inversely with frequency and reaching 120° at 50 c/s; moreover, to increase the subjective effect, this network was switched alternately into the left- and right-hand channels, thus changing the interchannel phase difference at each frequency by twice the angle shown on the curve, e.g. by 240° for a 50 c/s component of the signal. The resulting effects on the stereophonic presentation were then large enough to allow of an accurate assessment, and the observers were accordingly asked to indicate, by means of a numbered scale, how far the edge of the image moved when the network was switched from one channel to the other.

In order to assess the contribution made by different parts of the programme spectrum to the total effect, both of the experiments described above were repeated with the low-frequency range of the programme restricted by a high-pass filter attenuating 3 dB at 200 c/s and having an ultimate rate of attenuation of 12 dB/octave.

4.2.2. Results

Table 4 shows the percentage of tests in which the observer, on the introduction of the phase shifting network referred to in Fig. 3, curve (a), (90° at 50 c/s) reported a movement of the stereophonic image, or of some component of it, in the expected direction - i.e. away from that loudspeaker in which the signal was lagging in phase.

TABLE 4

LOWER FREQUENCY LIMIT 40 c/s			LOWER FREQUENCY LIMIT 200 c/s		
ORGAN	DRUM	DOUBLE-BASS	ORGAN	DRUM	DOUBLE-BASS
93%	99%	93%	86•5%	86•5%	87•5%

Although the displacements were too small to be accurately measured, the figures in the table are far above the 50% which could have been obtained by chance. A remarkable feature of these results is the high score obtained with programme material restricted to the range above 200 c/s, at which frequency the interchannel phase shift introduced by the all-pass network was only 22•5°.

Table 5 shows the displacement of the edge of the image when the phase-shifting network referred to in Fig. 3, curve (b) (120° at 50 c/s), was switched from one channel to the other. The displacement is expressed in terms of the stage width, followed, in brackets, by the standard error (S.E.) of the mean.

TABLE 5

	LOWER FREQUENCY LIMIT 40 c/s			LOWER FREQUENCY LIMIT 200 c/s		
	ORGAN	DRUM	DOUBLE-BASS	ORGAN	DRUM	DOUBLE-BASS
Listening Room	0•053 (S.E. 0•008)	0•108 (S.E. 0•009)	0•059 (S.E. 0•007)	0•047 (S.E. 0•006)	0•062 (S.E. 0•004)	0•032 (S.E. 0•005)
Dead Room	0•077 (S.E. 0•011)	0•096 (S.E. 0•009)	0•082 (S.E. 0•012)	0•062 (S.E. 0•008)	0•059 (S.E. 0•008)	0•048 (S.E. 0•007)

It will be seen that in the passages for drum and for double-bass, removal of components having frequencies below 200 c/s produced a significant reduction in the observed displacements. For the organ music, however, this reduction was not large enough to be statistically significant; since the spectrum of the test passage was known to contain strong components at frequencies as low as 40 c/s, it must be assumed that the directional effect of components above 200 c/s was predominant.

The effect of acoustic environment is seen to be appreciable in most cases. The image displacements for the organ and double-bass - with or without restriction of the frequency range - are significantly smaller in the listening room than in the dead room; for the drum the effect of room acoustics is not significant. It is also of interest that the results obtained in the dead room for each of the three instruments for either one of the frequency ranges are substantially the same; on the other hand, those obtained in the listening room are significantly different for each instrument, at least for the particular excerpts chosen.

5. CONCLUSIONS

From the foregoing data, it is possible to make a rough estimate of the interchannel phase tolerance which might be imposed on a compatible stereophonic system. The various limiting factors are presented in Fig. 4. Curve (a) in Fig. 4, reproduced from curve (a) in Fig. 3, shows a form of interchannel phase shift

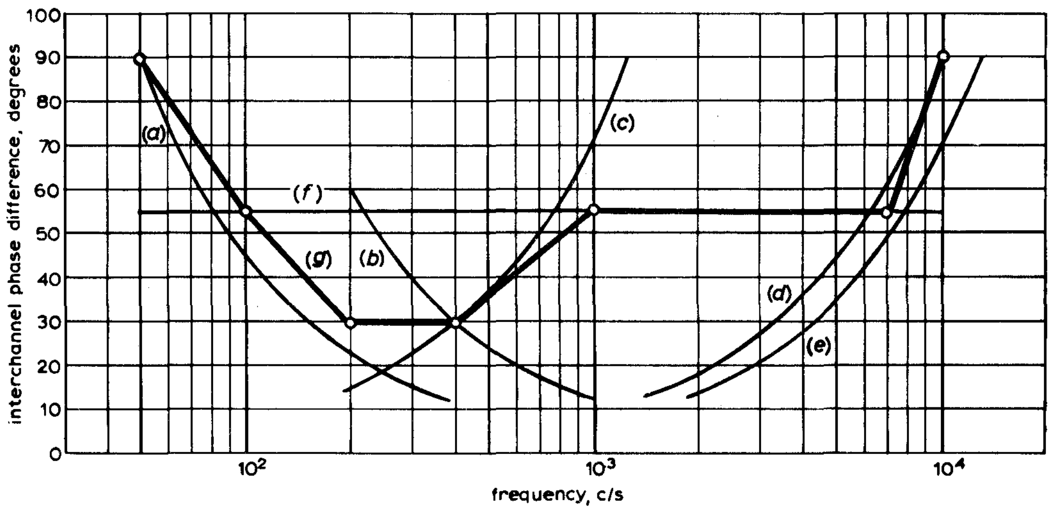

Fig. 4 - Derivation of overall tolerance for interchannel phase difference:

Curve (a):	Interchannel phase difference inversely proportional to frequency, reaching 90° at 50 c/s.
Curve (b):	Interchannel phase difference inversely proportional to frequency, reaching 240° at 50 c/s (region above 200 c/s only).
Curve (c):	Interchannel phase difference proportional to frequency, corresponding to 200 μs interchannel time difference.
Curve (d):	Interchannel phase difference proportional to frequency, reaching 90° at 10 kc/s.
Curve (e):	Interchannel phase difference proportional to frequency, reaching 90° at 13 kc/s.
Curve (f):	Interchannel phase difference constant at 55°, corresponding to 1 dB maximum loss of compatible signal.
Curve (g):	Tentative suggestion for overall tolerance.

characteristic for which, as shown in Section 4, the effects on both monophonic quality and stereophonic presentation observed on programme are detectable but not serious.

The image displacement corresponding to curve (a) in Fig. 4 was too small to measure accurately, but may be estimated from Table 5, on the basis of rough proportionality, to be not greater than 0·04 of the stage width for the most critical type of programme material. Curve (b) in Fig. 4 shows the overall change in interchannel phase difference at frequencies above 200 c/s produced by switching the network having the phase characteristic shown in Fig. 3, curve (b) from one channel to the other; the corresponding image displacement, from Table 5, is seen to be not greater than 0·06 of the stage width. Thus, a tolerance curve intended to restrict unwanted image shifts to around 0·05 of the stage width could safely be placed somewhere between curves (a) and (b). Curve (c) in Fig. 4 shows the interchannel

phase difference corresponding to an interchannel time difference of 200 μs, which, as already noted, has been proposed as a tolerance limit, and it seems logical to use this law as a rough guide from about 400 c/s upwards.

As far as the high frequency components of the programme are concerned, it will be seen from Table 3 that for frequency bands extending respectively to 13 kc/s and 10 kc/s, interchannel phase differences proportional to frequency and reaching 90° at the upper end of the band are tolerable; these two conditions are represented in Fig. 4 by curves (d) and (e) respectively. It should be emphasized that curves (a) to (e) give in each case the phase characteristics for a particular circuit condition which has been found acceptable on programme, but should not be taken to represent the acceptable degree of phase displacement at any one frequency considered separately.

To complete the picture it is necessary to note that interchannel phase differences occurring over a wide frequency band may lead to undermodulation of the transmitter. While therefore an interchannel difference of 90°, corresponding in the worst case to a loss of 3 dB in the compatible signal, may be allowed at the extremes of the frequency band, which carry only a small part of the total signal energy, this condition could not be tolerated over the whole frequency band. If, for example, the degree of undermodulation arising from the interchannel phase difference is not to exceed 1 dB, then an overriding limit of 55°, represented in Fig. 4 by the horizontal straight line (f), must be imposed over the central part of the frequency range.

In the light of the above, it is now possible to formulate tentative tolerance figures for interchannel phase difference. Any interpretation of the data for this purpose must necessarily be somewhat arbitrary, but as a starting point for discussion it seems safe to allow 90° at 50 c/s and at the upper limit of the band - for example at 10 kc/s - and 30° from 200 c/s to 400 c/s, introducing the 55° limitation (1 dB loss in the compatible monophonic signal) at 100 c/s and at frequencies between 1 kc/s and 7 kc/s. The result is represented in Fig. 4, curve (g), in which the points thus defined are joined by straight lines.

6. ACKNOWLEDGEMENTS

Acknowledgement is due to Dr D.J. Neale, who assisted in the experiments described above, and to Messrs. R.L. Deane and K.H. Hewitt, who constructed the apparatus used.

7. REFERENCES

1. Leakey, D.M., 'Further Thoughts on Stereophonic Sound Systems', Wireless World, Vol. 66, No. 4, April 1960.

2. Shorter, D.E.L., 'A Survey of Stereophony as Applied to Broadcasting', Proc. I.E.E., Part B, Supplement No. 14, March 1959.

3. Hanson, R.L., 'Psychoacoustics of Stereophonic Reproduction', paper presented at I.R.E. Convention, New York, March 1960.

4. 'Summary of the Results of Measurements made on the Audio-Frequency Parameters', E.B.U. Working Party S (Stereophony), Com.T.(S) 38-E, 21st February 1962.

5. 'Phase Characteristics of Music Lines for Stereophonic Transmission', Designs Department Technical Memorandum No. 2.118 (62).

6. 'The Effect of Crosstalk at High Frequencies Between Left and Right Channels on Stereophonic Reproduction', Research Department Report No. L-049, Serial No. 1961/17.

7. 'Some Experiments on the Subjective Effect of Limiting the Upper Frequency Range of Programmes', Research Department Report No. L-034, Serial No. 1957/10.

8. Schiesser, H. and Jakubowski, H., 'Der Einfluss von Phasen- und Laufzeitunterschieden bei der Übertragung von Stereosignalen', Rundfunktechnische Mitteilungen, Vol. 7, No. 3, June 1963.

APPENDIX

At the meeting of the EBU Working Party S, held in Hamburg on 10th to 13th December 1962, the question of tolerances on the unintentional phase differences between the left- and right-hand signals of a stereophonic programme was

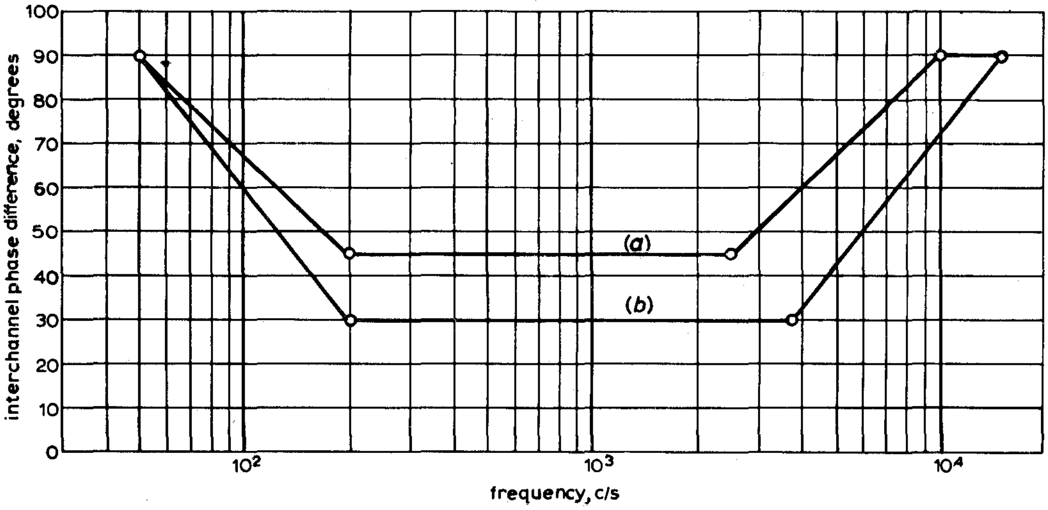

Fig. 5 - Interchannel phase difference as a function of frequency. Tolerance accepted by EBU and approved by CCIR 1963

Curve (a): acceptable limit, if necessary
Curve (b): limit of perceptibility

considered. Discussion of the results given in this report, together with the results of experiments carried out by IRT[8] and RTF led to the adoption of the limits shown in Fig. 5, which were subsequently approved by the Xth Plenary Assembly of the CCIR.

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